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TOXIFICATION OF PLANTS BY ORGANIC INSECTICIDES

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(Paper submitted to the Plant Protection Section of the Academy.)

The high toxicity of such modern insecticides as DDT, hexachlorane, "Preparat No. 47" and thiophos, and their ability to penetrate into the tissues of plants, * led us to initiate certain researches on the toxification of plants.

Experiments in 1950 showed that the insecticide penetrates into the plant not only when it comes in contact with the root system, but also when it is put on the leaves. Thus, for instance, filaria introduced along with the soil in pots were killed by dusting the leaves of cabbages planted in the pots. In the present paper, we are mainly reporting the results of experiments on the toxification of the plants by way of the roots, and only isolated instances will be cited of penetration by way of the leaves.

Our first task was to establish the fundamental factors determining the penetration of the insecticide into the plant and its accumulation in the plant tissues. In this connection we succeeded, first of all, in establishing that the penetration of the insecticide into the green parts of the plant by way of the root system takes place very rapidly. Thus, for instance, it was established by tests with potted corn plants that in fifteen minutes' time after a single watering with a 0.0001% solution of hexachlorane the leaves of the plant became toxic, and that a single feeding of these leaves to larvae of the Asiatic locust ** results in a mortality of about 25% of these insects.

On the basis of our experiments with different plants, it may be stated that the initial distribution of the insecticide in the different parts of the plant is highly non-uniform.

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* Ye. N. Kozlova. On the penetration of organic insecticides into plant tissues. Dok. Vses. Ord. Lenina Akad. Sel'sk. Nauk imeni V. I. Lenina, No. 3, 1950.

** *Locusta migratoria.* (Tr.)

Under laboratory conditions, when willow caterpillars * were fed with poplar leaves from branches which had stood in aqueous solutions of insecticides, we obtained completely different percentages of mortality with leaves taken from different levels on the branch. The lower leaves gave 76.1% mortality, the middle leaves 61.7% and the top leaves 49.7% (of 40 caterpillars in each group).

When we turned from cut branches to whole, normally growing plants, we were able to convince ourselves that this non-uniformity was connected with the different ages of the various parts of the plant, for instance the leaves. Thus observations on the population-dynamics of peach-aphis** on indoor plants (Chinese roses) given a single watering DDT solution, showed that in three or four days after this watering, the toxicity of leaves which were on different levels on the plant at the time of watering finally evened up. The decreases in the aphis populations on the upper and lower leaves varied correspondingly: after 24 hours these populations were decreased 5.4% and 44.8% respectively; after two days, 23.8% and 62.2%; after three days, 82.7% and 91.4%; after four days, 92.4% and 92.5%. However, new leaves which grew out exhibited a lesser degree of toxicity than the older ones. Consequently the equalization of the degree of toxicity in the upper and lower leaves may very probably be explained by the aging of the former. The most likely assumption is that in the young growing leaves the molecules of toxic substances are more quickly broken down and converted into substances non-poisonous to insects. Thus we arrive at the concept, confirmed by subsequent experiments, of a continuous destruction of the plant's intake of insecticide, with the degree of toxicity of the plant tissues determined by the balance between the processes of intake and destruction of insecticide at any given time.

Since the young growing parts of the plant have a higher activity of biological processes, we decided to find out how variation of the lighting, which determines photosynthetic activity, would show up in the accumulation of the toxic agent in the plant. For this purpose, wheat shoots infested with peach aphis were grown in the dark and under artificial light. On the fifth day after an irrigation with DDT solution (calculated at 1.2 kg of the active principle per hectare), a marked reduction of the aphid population (50.3% of 1225 insects) was noted on the plants in the dark, while the insect population on the plants grown under incandescent lamps (illumination-intensity about 400 luxes) failed completely to differ from the controls.

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* This insect (Russian *ivovaya volnianka*) has not been identified with certainty by the translator. It may be *Plussia salicis*.

** *Myzodes persicae*. (Tr.)

Further confirmation of the relationship between accumulation of the toxic agent in the plant and the physiological activity of the plant was obtained in an experiment with corn shoots (at the stage when the second pair of leaves were beginning to appear). The experiment was conducted under greenhouse conditions with natural lighting, the daytime intensity of which (from 9 to 19 o'clock) during the period of the tests (March 1 to 5) was 170-200 luxes.

At 9.30 a.m., all the plants were irrigated with a 0.0001% solution of hexachlorane, calculated at 0.75 mg of the active principle per plant. At different intervals of time after the watering, the first two leaves were taken from a number of plants and given as food to Asiatic locust larvae in the first instar (twenty in each group), which on the succeeding days were supplied with non-toxic food. The mortality data thus obtained, with a correction for the mortality of the control insects, are shown in Fig.1. If we consider that the mortality curve reflects the daily variation in the hexachlorane accumulation in the leaves of the plants, we must recognize that the content of insecticide even in the same leaves of the plants differs with the time of day, and that during the days immediately after the watering there are hours in the twenty-four when they have no poison in them at all, or retain very little of it. It seems to us highly probable that the peaks of the curve correspond to the intensity-minima of the photochemical process in the leaves of the plants. On the other hand, at those hours of the day when the said process is most active (in the present experiment, at noon), the insect mortality curve, and consequently the insecticide content, falls to zero. The regular character of the diurnal cycle of toxic accumulation is confirmed by a second experiment similar in all respects to the first, which was carried out on the 12th of March. The mortality curve obtained was very like the first one (except for a small displacement of the peak), and is also shown in Fig.1.

In this test, a number of plants was set aside for an extended observation on the dynamics of the accumulation of the toxic agent in the leaves. Seven times in the course of fifteen days, each time at 9 a.m., the first pair of leaves was taken from certain plants in this series and placed for twenty-four hours in insectaria housing locust larvae (4 groups of 5 larvae each). The results obtained (Fig.2) show that during the first five days a gradual accumulation of insecticide takes place in the leaves.

After this, the toxicity of the leaves becomes less and less each day, and in fifteen days time it causes only 6.7% mortality. Thus we may consider that in this experiment the bulk of the insecticide introduced into the soil in watering had, at the end of 15 days, been taken up by the plants and, through the effect of the vital processes of the latter, had ceased to exist as a poison for insects.

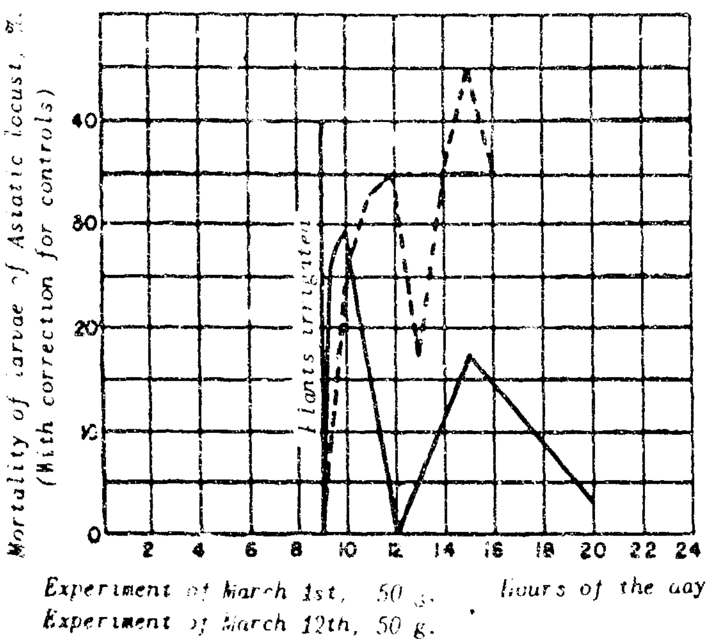

Fig. 1. Dynamics of hexachlorane accumulation in leaves of corn plant

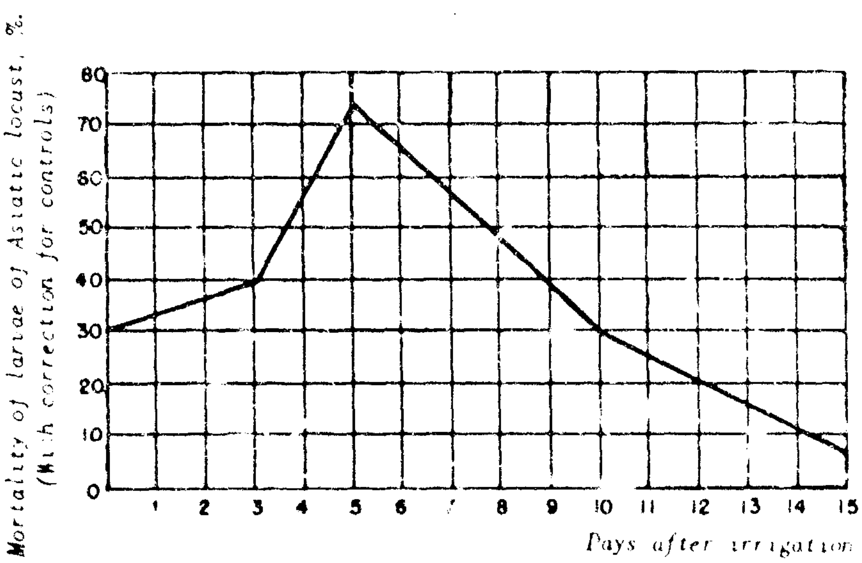

Fig. 2. Duration of period of toxicity of corn plant after watering with hexachlorane solution.

The question of the intensity of the insecticide accumulation in the plant and the duration of the toxic period are questions of paramount importance for the application of the method of toxifying plants through the soil.

Under natural conditions, however, the dynamics of the poison in the plant becomes a much more complicated process, dependent on a whole complex of factors. Of outstanding significance among these factors are the degree and duration of contact between the root system and the insecticide, these factors in turn being determined by the methods of applying the insecticide and the dosages. Thus when "beet-bugs" * were placed on /sugar/ beet shoots (Krasnodar Territory), the following mortalities were observed on the next day: With seeds planted after a 24-hour soaking in hexachlorane solution, 31.2%; with seeds planted after dusting with hexachlorane powder (3.4 kg per 100 kg), 62.5%; with hexachlorane introduced into the soil (90 kg per hectare), 68.7%. Data of the same nature obtained in a number of other tests are given in Table 2 and Fig.3.

According to our tests, the introduction of the insecticide into the soil guarantees, as a rule, the greatest degree and duration of plant toxification.

Nevertheless, for purposes of controlling a large number of harmful insects infesting the early vegetative phases of food plants, entirely satisfactory results may be obtained by sowing seed dusted with the insecticide. This appears from the example just cited (the rendering of beet plants toxic for "beet bugs"), from the data of Table 2 on the experiment with early wheat, and also from a large amount of factual material obtained through the efforts of various research organizations in 1950 on the toxification of grain plants with hexachlorane as protection against the Swedish fly.** The possibility of using very small quantities of insecticide for the toxification of planted seed, for instance 1 to 1.5 kg of 12% hexachlorane powder to dust 100 kg of seed grain, justifies our regarding this method as the most applicable for wide practical employment.

The importance of norms for the amount of insecticide used will be seen from the data presented in Fig.3 (curves of mortality of spider mite *** on leaves of cotton plant as a result of a single irrigation with insecticide solutions of three different concentrations); also from data re the effect, on eurygaster and the Asiatic locust, of a pre-seeding application of hexachlorane to the soil, in doses of 10 to 20 kg per hectare (Table 2), and so forth.

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* *Poecilloscytus cognatus*. (Tr.)

** *Oscinosoma frit. L.* (Tr.)

*** *Epitetranychus bimaculatus* . Hanst. (Tr.)

An exceedingly important factor in the duration of toxicity of the plant for insects is the relative stability of the insecticides themselves during the time they are in the soil and in the plant tissues. For examples we refer the reeder to the day-by-day mortality curves for spider-mite on cotton plants, curves obtained in plot-experiments on the irrigation of plants with insecticide solutions of concentration 0.0015 (these dilutions were produced by the use of intermediate solvent OP-7). As is seen in Fig.4, the mortality of the insects from DDT and hexachlorane gradually increases over the whole of the period considered. On the other hand, when thiophos and "Preparat No. 47" were used, the mortality reached its maximum by the fifth day after irrigation; that is, after five or ten days the plants became less toxic to the insects.

In our very first experiments on the toxification of plants we established the great importance of soil humidity for the access of the insecticide to the root system of the plants. In this connection a great deal of information is yielded by the analysis of material obtained in the work carried out in 1950 by the Plant Protection Stations and Centers of the All-Union Institute of Plant Protection, on the use of hexachlorane in combatting the Swedish fly. It was found that in geographic zones where there is abundant precipitation during the one to one-and-a-half months after the sowing of early crops, toxification with hexachlorane as a rule protected the planted crops from the depredations of the Swedish fly, and in contrast, when there was little precipitation the hexachlorane toxic effect, exerted by way of the plant, was completely absent.

On this basis we may consider that the most favorable conditions for developing a toxification of plants should be found in regions where irrigation is used in agriculture. The first orientation-experiment under such conditions was organized by us in 1950, using DDT preparations, hexachlorane, No. 47 and thiophos on cotton plants during the fourth or final irrigation (Azerbaidjan SSR, Mugan Land-Improvement Research Station). The insecticides were used in the form of solutions with concentrations 0.0005, 0.001 and 0.0015%, with the ordinary normal irrigation of 800 cu.m. per hectare. OP-7 was used as the intermediate solvent, in a calculated dosage of 0.01%. The results obtained are shown in Table 1 and Figs. 3 and 4.

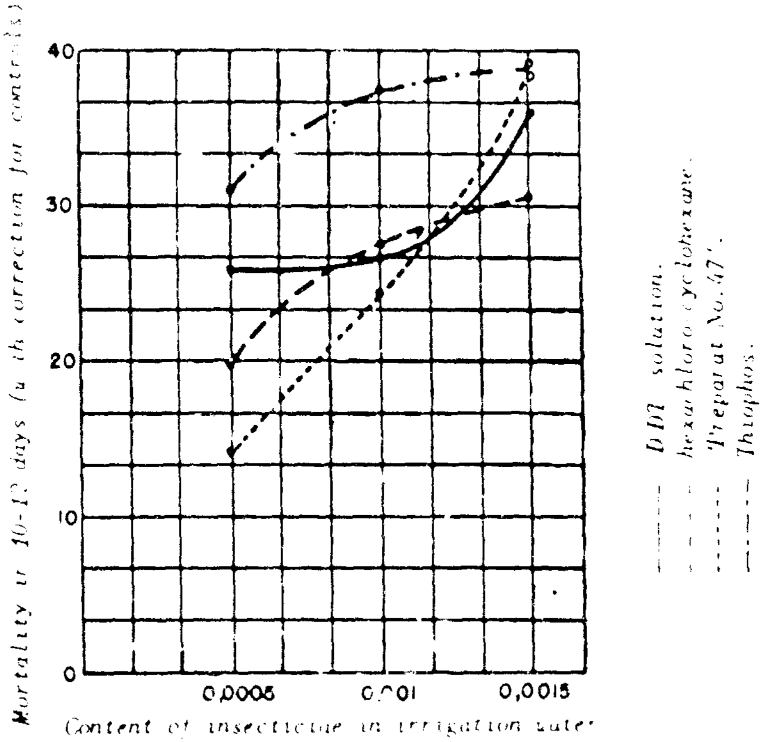

Fig.3. Mortality of spider-mite, %.

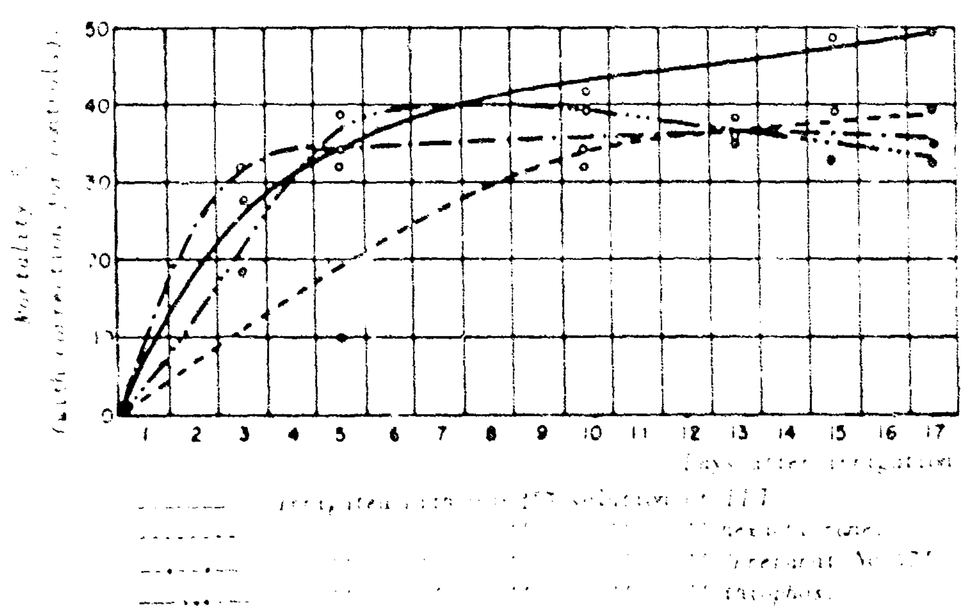

Fig.4. Mortality of spide.-mite, tabulated by days.

Table 1

Insecticide	Content of insecticide in irrigation water (%)	Reduction in numbers of cotton aphis * in 17 days (%)	Mortality (with correction for controls).	
			Cobweb Mite after 17 days	Caterpillars of cotton stem-borer ** (3rd instar) after 5 days +
DDT (technical)	0.0015	69.7	49.5	50.0
Hexachlorane (technical)	0.0015	52.8	45.9	35.6
No.47 (technical)	0.0015	71.1	38.8	16.7
Thiophos (technical)	0.0015	38.6	38.8	4.7

+ Since there were no stem-borer caterpillars in the region where the tests were conducted, an artificial infestation was carried out on the tenth day after the irrigation, with gauze screens used for isolation purposes.

Considering that the tests were conducted during the period least favorable for toxification operations (from August 21 to September 8), we may conclude that the use of insecticides at the proper time (during the first irrigations of the cotton) would guarantee us a great reduction in the insect population.

The data obtained permit us to consider that all the insecticides tested possess the ability to penetrate through the root system into the tissues of the plants, and are active intestinal poisons for all three of the insects in the experiment. Among the preparations applied, the most universal effect is shown by DDT, which had the greatest efficacy against all three of the pests.

Comparison of the data for the three insects in Table 1 shows that the cotton aphis and the spider mite are more sensitive to all four of the preparations than the cotton

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* *Aphis frangulae* Kalt. (*gossypii* Glov.). (Translator.)

** *Chloridea obsoleta* F. (Translator.)

stem-borer caterpillars; that is, from the data obtained we may conclude that the sucking insects are more sensitive to the intestinal action of organic preparations than the chewing insects. This conclusion finds support in experiments in which beet plants were toxified with "beet bugs" and "beet weevils".* In all variants of the experiment, 100% mortality of the beet bug was secured by the third day. In contrast to this, the highest weevil mortality was only 66.7% on the seventh day, even, in a test with 90 kg of insecticide applied per hectare of ground.

Results of plot tests on wheat toxified with hexachlorane are also in complete agreement with the theory as stated above.

When the insects were placed on the plants, the larvae and adults of *Eurygaster intergriceps* Put. were in first and second place as regards mortality; for the Asiatic locust the percentage of mortality was considerably less. Thus, for instance, in a version of the experiment in which dusting of the seed was employed, the toxification of the plants produced the following effects: decrease in numbers of eurygaster larvae, 67.5%; mortality of adult eurygaster, 50%; of the Asiatic locust larvae, 42.8%.

Along with the dissimilarities in group resistance associated with the manner in which the insects feed, we must also take into consideration differences of species and age in the resistant insects. When various caterpillars were fed on poplar and apple branches, both of these with their ends immersed in the same solution, on the twenty fifth day the mortality figure for willow caterpillers was 60.3%, for brown-tailed moth caterpillars * 29.2%, and for the tent caterpillars, 16.7%. Moreover in this test the willow-caterpillar was most sensitive to "Preparat No.47", while the tent caterpillar was most sensitive to the action of hexachlorane.

Examination of the data from this section of the experiments shows that the toxification of plants should be effected with that insecticide which is most active against the insect (or group of insects) for which it is used, and moreover at as early as possible a stage in the development of this insect (or insects). Even when these conditions are met, however, the toxification method does not guarantee success against all insect pests. With the exclusively intestinal action characteristic of this method, insects which are very resistant to a given insecticide can scarcely be destroyed by the extremely small doses of the toxic agent which may be introduced into their organism from the tissues of the food-plant.

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* *Nygmia phaeorrhoea.* (Tr.)

Nevertheless the employment of insecticides by the plant toxification method considerably enlarges the possibilities of the new organic poisons in the combatting of a large group of sucking insects, including those the integuments of which are not very penetrable to the contact-action of, for example, chloro-organic compounds. Not only in connection with certain species of aphis, phytophagous bugs and the cobweb mite, but also against such targets as scale-insects of the Lecanium and Aspidiotus species we have secured, under laboratory conditions, mortalities of 90% and over by means of plant toxification.

It was of considerable interest to us to demonstrate the practicability, in principle, of using plant toxification against such an important pest as eurygaster. With this in view, we arranged certain small-scale plot-tests in Slaviansk District, Krasnodar Territory, on the hexachlorane toxification of early wheat by way of both pre-seeding and postgerminal treatment.

Seeding was carried out on the 22nd of April, that is, later than the usual seeding time. Shoots were seen the 1st of May. For the postgerminal experiments, the soil was treated with the insecticide preparation on the 7th of May. In the period between seeding and germination, the area was irrigated. Fifteen days after the appearance of the shoots, eurygaster eggs were placed on the plants, and after 25 days adult insects, caught in the field, were placed in cages on the plants in the test plots. The results of the population-counts of larvae and adults on the 8th June, that is on the 12th day after introduction of the adult insects and the 22nd after that of the eggs, are shown in Table 2. For comparison, we also show the mortality figures for larvae of the Asiatic locust (first instar) fed with shoots from the treated plots.

The data in Table 2 show that the toxification of the plants with hexachlorane led to a very considerable percentage of destruction of both the larvae and the adults of eurygaster, in all the variants of the experiment.

In a later series of laboratory experiments it was established that DDT too is an intestinal poison for eurygaster, but one which is, however, somewhat less active than hexachlorane. In Table 3 we show the mortalities for larvae in the first, second and third instars, fed on cut wheat plants standing in an aqueous DDT solution.

Table 2

Preparation	Method of Application	Concentration of active principle (in kg/ha)	State of the plants on the 12th day after appearance of shoots.		Reduction in number of eurygaster larvae (% of number of eggs).	Mortality of adult eurygaster (in %, with correction for controls).	Mortality of larvae of Asiatic locust (in % with correction for controls).
			Stems per single plant	Leaf area in sq. cm. per 100 cm.			
6% hexachlorane dust	Pre-seeding application to the soil	20.0	1.3	399	99.2	78.5	63.6
6% hexachlorane dust	Pre-seeding application to the soil	10.0	1.3	324	79.8	42.0	16.6
6% hexachlorane dust	Applied to the soil around shoots	20.0	1.3	538	80.7	42.3	33.4
6% hexachlorane dust	Dusting of seed	0.6	1.5	611	67.5	50.0	42.8
Controls	———	-	1.1	147	-	-	-

Table 3

Subject	No. of insects in test	Mortality of larvae (in % with correction for controls).		
		After 2 days	After 4 days	After 5 days
Eurygaster larvae				
Instar I	418	44.5	78.4	86.5
Instar II	165	43.0	53.8	61.8
Instar III	175	0.0	20.8	-

DDT and hexachlorane, in those quantities which penetrate into the tissues of "toxified" plants, have an intestinal action on the larvae of eurygaster; the establishment of this fact gave us a key to the reasons for the prolonged toxic effect of DDT when used in the ordinary manner against this insect pest.

In our tests, carried out at Kuban in conjunction with a crop protection field-expedition during the period from the 10 to 20th May, 1950, aerosols of DDT solution in petroleum oil were tried out against eurygaster on the shoots of grain plants. Use of aerosols under the said conditions gave practically no results; the mortality of insects did not exceed 10% (Table 4), and after the treatment the number of insects in the test plots (with the exception of one plot) was greater than for the controls.

We suggest that the observed reduction in the number of larvae is mainly due to the toxification of the plants with the insecticide which penetrates into the plant tissues and persists there at least until the mass hatching of larvae of instar I.

A very striking reduction in the numbers of eurygaster larvae, amounting to as much as 97.4%, was also observed in tests on combatting eurygaster by dusting with DDT; tests carried out in Krasnodar and Stavropol Territories.

The effect of earlier applications of the insecticide on the numbers of the succeeding generation, by way of plant toxification, may be regarded as an indirect "delayed action" of organic insecticides. The data obtained give us grounds

Table 4

Crop and locality	Date of treatment	Size of test plots	Insecticide preparation	Norm for application of active principle (kg/ha)	Mortality of adult insects in % on the 5 to 7th day of tabulation	Number of insects per sq. m., on 5th to 7th day of tabulation	Number of larvae per sq. m., 35 to 40 days after treatment	Reduction of numbers of larvae in %, 35 to 40 days after treatment
Winter wheat, Second Brigade of the Stalin Kolkhoz, Slaviansk District, Krasnodar Territory	11 May	4 ha	10% DDT in Diesel fuel	0.29	0	2.88	55.4	+7.3
	11 May	4 ha	20% DDT in Diesel fuel	0.53	7.3	4.16	28.8	40.1
	16 May	18 ha	10% DDT in Diesel fuel	0.55	9.6	2.32	22.2	53.8
	16 May	16 ha	15% DDT and 10% hexachlorane in Diesel fuel	1.07 + 0.71	10.0	3.13	13.6	71.7
		8 ha	Control	-	0.0	2.76	48.1	-

for supposing that when organic insecticides of high toxicity are used in any form and according to any method of combatting the insect pests of different crops, it is always possible to have the effect increased to some extent by the quantity of poison which is taken up in the tissues of the plants.

This "delayed action" of plant toxification and the additional effect which it produces may in some cases be of real practical importance, as for instance in combatting eurygaster.

In the carrying out of our experiments, it was revealed that the use of insecticides for toxification of plants against pests simultaneously brings about an intensification of the growth-processes of the plant. This appears from the data of Table 2, from our field observations on the development of beet-plants under the influence of DDT and hexachlorane introduced into the soil, and from a great amount of factual material obtained by numerous research scientists on the pre-seeding application of hexachlorane for the protection of seeded grain crops against the Swedish fly, and so forth.

These observations all give us grounds for supposing that the toxification of plants with organic insecticides and the above-mentioned stimulating effect are both due to one and the same cause, namely the penetration of insecticide into the tissues of the plants.

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